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ABSTRACT

This paper states and discusses general guidelines in teaching for conceptual change. Several important factors that seem to be necessary in meeting the guidelines in normal classrooms are considered. The factors relate to the teacher, student, and the classroom climate. The guidelines are illustrated using examples drawn from a fifth-grade classroom of 13 students at a small parochial elementary school where conceptual change teaching is practiced. The guidelines in teaching for conceptual change are as follows: (1) students' ideas need to be an integral part of classroom discourse; (2) the status of ideas needs to be discussed and negotiated; (3) the justification for ideas needs to be an explicit component of the curriculum; and (4) the discourse of the classroom needs to be explicitly metacognitive. Each guideline is discussed with specific instructional applications provided. Questions that remain unanswered after exploring the research literature and some general limitations of the guidelines are examined. (DDR)

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TEACHING FOR CONCEPTUAL CHANGE: EXAMPLES FROM FORCE AND MOTION

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Introduction

The critical role that students' current knowledge plays in any intellectual activity is widely accepted. So too are the findings that there is considerable diversity in students' current knowledge, that the diversity frequently contradicts accepted views, and that much of it seems unresponsive to instruction. All of this provides support for thinking about learning, not as simply an accumulation of information, but as a process of conceptual change. This raises two issues: what learning as conceptual change means; and what a conceptual change view of learning says about teaching.

With respect to the first issue, we use a model of learning as conceptual change initially proposed by Posner, Strike, Hewson, and Gertzog (1982) and discussed further on a number of occasions (Hewson, 1981, 1982; Hewson & Thorley, 1989; Strike & Posner, 1985, 1992; Thorley, 1990). The central concepts of the model are **status** and **conceptual ecology**. The status that ideas have for the person holding them is an indication of their intelligibility, plausibility, and fruitfulness. The conceptual ecology includes other knowledge the person holds that interacts with these ideas in the process of determining and changing their status. These concepts are discussed more fully in the articles referred to above.

With respect to the second issue, we recognize that the conceptual change model is a learning model. Learning models do not prescribe teaching. They can, however, be used to critique teaching, since suggested teaching strategies and sequences can be examined to see whether they facilitate or hinder learning outlined by a particular model. An examination process such as this can lead to the identification of general guidelines that are consistent with the model, and function to eliminate what is inconsistent with it rather than prescribe what is necessary. Teaching that explicitly aims to help students experience conceptual change learning and that meets guidelines consistent with the conceptual change model we

shall call *teaching for conceptual change.*

Different authors have discussed the implications for teaching of student conception research and conceptual change learning. This literature, reviewed recently by Scott, Asoko, and Driver (1992), has suggested a number of different approaches. Common to all of them is the importance they attach to students' knowledge prior to instruction. Some, however, regard this as an opportunity--the foundation for future learning--while others see it as a problem to be overcome. It is also implicit in all approaches that the role of the teacher is a critical one in both choosing and implementing the curriculum. There is, however, variation in the envisaged roles for students, primarily with respect to the extent of control they might have over the course of instruction. The guidelines outlined below draw much from this ongoing debate.

In this article, we first state and discuss general guidelines in teaching for conceptual change. We then consider several important factors that seem to be necessary in meeting these guidelines in normal classrooms; these factors relate to the teacher, the students, and the classroom climate. Finally, we illustrate these guidelines using examples drawn from a classroom where conceptual change teaching is practiced.

Guidelines in Teaching for Conceptual Change

We expect that a range of different teaching activities could meet these guidelines. Further we do not imply a temporal or sequencing teaching order by listing these guidelines in a particular order. Analytically, these guidelines represent different purposes that might be achieved concurrently, depending on the chosen classroom activity.

Students' ideas need to be an explicit part of classroom discourse

In teaching for conceptual change, it is necessary that the range of views related to the topic held by different people in the class be made explicit. These views need to be contributed by both teacher and students. In the process, people will become aware of, and learn to value, ideas that they had not previously encountered or considered seriously. These ideas could either be ones contributed by others or ones that they themselves held but to which they had not paid much attention.

One part of this guideline is found in all normal teaching, since teachers have always made their views explicit in teaching the goals of the topic. There are, however, two significant differences from common practice. The first is the consideration of students' views as playing an important role in their learning. This step has been widely advocated in recent literature, but is still not the case in most classrooms. When only the teacher's views are explicitly stated, some students may be aware that their own individual ideas are different from those of the teacher, but be unaware of the views of other students. Equally as important, there is no encouragement for students to take their own ideas seriously; leading possibly to the unintended consequence of students devaluing their own ideas. This guideline points to practice significantly different from this.

The second difference from common practice is that students' views should be considered in similar ways to the teacher's view. This stands in contrast to most science classrooms where presentation of the textbook ideas is central and students' ideas are seldom, if ever, addressed. Considering students' views in such a way may seem surprising since the teacher's view will probably be more completely developed, more acceptable to the science community, and is the intended learning outcome of teaching. The intent of this aspect of the guideline is to ensure that students choose between different views on the basis, not of who said them, but of how good an explanation each provides. In doing so, they should come to recognize

that the source of authority for a given idea should not be the teacher's undoubted position of power, but the standards of evidence accepted by the discipline. An important consequence of this point is that students are constantly providing teachers with the current state of their ideas; i.e., elicitation becomes a ubiquitous aspect of classroom practice. Further implications for teachers, students, and classroom climate are considered below.

Some ways of making the views of all students explicit at the start of a new section are the following:

1. A teacher starts a topic with a non-credit quiz, answered individually, that includes questions having a range of options that represent common different views. After the quiz, the teacher identifies the range of answers in the class and asks students to explain their choices. (Minstrell 1982)

2. A teacher provides some demonstrations to introduce the context of the work. Students individually work through elicitation activities, discuss their responses in pairs, prepare posters in groups of four to summarize their findings, and present their posters to the class. (CLIS 1987)

3. Students define what a particular term or concept means to them prior to instruction. (Hennessey, 1991) This technique is illustrated below.

<u>The status of ideas needs to be discussed and negotiated</u>

Teaching for conceptual change should lead students to consider different views, leading to the need for them to make informed choices. Possible choices might be a continuing preference for their prior views, an acceptance of more than one view, or a preference for a different view at the expense of their prior views. It is worth noting that making any of these choices does not require the **extinction** of rejected views. In the choice process, students are likely to find that some views become more, and others less, acceptable to them. In other words, the status of these views changes, with the status of some being raised and the status of others being

lowered. In certain cases, these changes may be interdependent, e.g., when a student changes his or her mind about two views that are mutually contradictory to him or her.

It is necessary to recognize that when a choice is made, it depends not only on the available options for choice, but also on the criteria for making the choice. These criteria, and the knowledge required to apply them, are part of each person's conceptual ecology. Since there is likely to be considerable variation between conceptual ecologies, it is likely that different people will make different choices. This notion of choice is tied into the guideline, since a person chooses one option over another because its status to him or her is higher. In other words, people use their conceptual ecology in making status determinations; these are probably implicit, only stated in status language on special occasions, but nevertheless are critical. For instance, a student rejects the view--a table exerts an upward force on a book to support it--because she cannot imagine how "a dead table knows how much to push up." (Hennessey 1991) This view has low status for her; she knows what it means, but she doesn't believe it. In other words, a need for her explanations to provide acceptable causal mechanisms is an important component of her conceptual ecology. Another student accepts this view because he explains the book's state of rest by using balanced forces, an explanation seen in other examples. In other words, his epistemological commitment--similar examples require similar explanations--is instrumental in raising the status of this view; it is the criterion he uses in making his choice. The guideline therefore suggests that a teacher needs to be aware of the importance both of the status of students' views and of components of the conceptual ecology, and to include both status and ecology considerations explicitly in classroom teaching (Hewson & Thorley 1989, Hennessey 1991).

Activities aimed at raising the status of particular ideas should therefore be a part of teaching for conceptual change. In this respect, it has much in common with

normal teaching. These activities might be to present and develop the ideas, to provide examples of them, to apply them in other circumstances, to give different ways of thinking about them, to link them to other ideas, etc. Activities aimed at lowering the status of other ideas should also be a part of teaching for conceptual change. These might be to explore their unacceptable implications, to consider experiences they are unable to explain, to find ways of thinking about them that point to their inadequacies. Whether any status lowering activity works for a particular student does require that the student sees the inadequacy of an idea; a common problem is that teachers often mistakenly assume that the discrepancy is as obvious to their students as it is to them. It is important to note that status raising and status lowering activities can occur simultaneously.

In many classrooms, teachers' practices do not lead to different views being considered. In such circumstances, the possible need for, and actions to facilitate, students' lowering the status of their prior views will not be an explicit part of classroom practice. If teachers do not provide the opportunity for this to take place, they could not, in our view, be regarded as teaching for conceptual change. That being said, it is important to note it is not necessary that teaching for conceptual change occur in order for conceptual change learning to happen: it seems more appropriate to regard conceptual change teaching as a catalyst for, rather than as a causal agent of, conceptual change learning.

The justification for ideas needs to be an explicit component of the curriculum

In conceptual change learning students determine the status an idea has for them. In order to do this, they have first to know what it is, i.e., find it intelligible, and then to decide whether or not they find the idea plausible, and/or fruitful. In order to provide a justification for such a status decision, students will bring to bear one or more criteria, these being important constituents of their conceptual ecologies in which they locate the idea being considered. We shall consider the basis

for some plausibility justifications; those for fruitfulness would be similar.

Finding an idea plausible can be achieved by believing it to be true, or finding it consistent with other plausible knowledge. There are at least two relevant categories of conceptual ecology components in considering plausibility. The first is metaphysical belief: that which is given, cannot be proved, the very nature of something. If an idea being considered by a student were to contradict a metaphysical belief he or she holds, that becomes grounds for deciding that the idea is not plausible. A student who does not accept that a table can exert a force to support a book placed on it, might do so because of his or her metaphysical belief in the nature of inanimate objects: how can they "know how much to push?"

The second category is epistemological commitment: the criteria a person uses in deciding whether or not knowledge is justified, is acceptable. One such commitment is to consistency. If a person finds that one idea is consistent in significant ways with another acceptable idea, that becomes grounds for deciding that the first idea is plausible. Seeing a book at rest on a table as similar to one at rest on an outstretched hand can lead to deciding that consistency demands a similar explanation: gravity counterbalanced by an upward force exerted unproblematically by the hand in the one case, and by the table in the other. Another such commitment is to causality. An idea might be regarded as plausible if there is a causal mechanism that explains it. An example is being able to imagine that a table might be composed of particles with spring-like forces between them that would push back when an object is placed on it. This can be a powerful way for a person to accept that a table could exert an upward force.

Determining plausibility and fruitfulness (whether or not the conceptual change language is used) is not a significant component of most classrooms, yet it is an essential part of conceptual change learning. This guideline points to the need for explicit consideration of the bases for determining status. While this guideline is

implicit in the previous one (the necessity of explicit status consideration), it is included to emphasize the essential role of constituents of a person's conceptual ecology in conceptual change learning.

The discourse of the classroom needs to be explicitly metacognitive

Teaching for conceptual change is explicitly metacognitive. The concept of metacognition refers to "knowledge concerning one's own cognitive processes and products.." (Flavell, 1976) Metacognition's cognitive process aspects have been accentuated in studies of other areas, e.g., reading, where it refers to the knowledge and control of factors that affect learning activity such as knowledge of oneself as a learner, the demands of the learning task, and the strategies employed in learning (Palincsar and Ransom, 1988). While these aspects are important for any forms of learning, knowledge of one's own cognitive products is particularly important in teaching for conceptual change. Thorley (1990) employed a helpful distinction, using the terms "metacognitive" and "metaconceptual" to refer to reflection on, respectively, cognitive processes and "the content of conceptions themselves." In other words, when students not only think **with** their ideas relating to a phenomenon, but also think **about** these ideas, they are being metaconceptual.

Why is metacognition, in general, and metaconception, in particular, a hallmark of teaching for conceptual change? When teachers elicit different explanations of a particular phenomenon or set of phenomena in a classroom, they are in effect laying out the explanations themselves as objects of cognition; this is being metaconceptual. When students comment on, compare, and contrast these explanations, when they consider arguments to support or contradict one or other explanation, and when they choose one of the possible explanations they are engaged in metaconceptual activities.

It should be clear that metaconception represents another way of describing the intent of the previous two guidelines, and is thus implicit within them. Making it

explicit does, however, serve to give metacognition an identity that, in our view, provides an important perspective in teaching for conceptual change.

Factors supporting Teaching for Conceptual Change

The Teacher

In teaching for conceptual change, teachers have different roles to play. One role is to be a facilitator who is responsible for establishing the classroom climate outlined below in order to facilitate student learning. This entails setting appropriate contexts for classroom activities, posing problems that have relevance and meaning to the students, exploring what underlies different ideas without threat to those who hold them, finding ways of helping students become dissatisfied with their own ideas, introducing tasks in which students apply newly acquired ideas. It also requires that she or he sets the ground rules governing all aspects of classroom interaction, discusses them explicitly with the class, and applies them consistently.

A second role is to be an active participant in the classroom. There is a major dilemma here. On one hand it is very easy for the teacher's voice to be the most powerful one in the class; in many classes it is the only one. On the other hand, the teacher can employ principles of discovery learning, with the assumption that all information comes from experience, i.e., the teacher's content voice is not heard. It is necessary to strike a balance between these two positions; it is as important to hear the teacher's view as it is to hear the views of the students. It is also as important that students feel as free to reject their teacher's views as it is to reject their classmates' views.

Playing these roles successfully requires important teacher characteristics. The previous sections point to some: a respect for and knowledge of learners and their ideas, an understanding of the historical development of concepts as it relates to students' learning paths, and a wide repertoire of appropriate teaching strategies and supporting materials. Implicit in all of these are the teacher's conceptions of the

nature of learning, of teaching, and of science, that are supportive of teaching for conceptual change. These have been outlined elsewhere (Hewson & Hewson 1988).

The Learner

Students have particular roles in classrooms with teachers whose goal is teaching for conceptual change. They need to become learners who are convinced that the goal of learning should be to **understand** the topic being considered and, in doing so, to make it their own. They thus need to accept responsibility for their own learning, become aware of their own ideas and their reasons for accepting them, trust their own thinking, and justify their conclusions using sensible arguments. In doing so, however, they need to recognize that there might be different views of the same event, and that those views need to be respected and evaluated in relation to their own ideas. When different views are expressed, students need to listen to and understand these views, and negotiate common meanings. Finally, they should be prepared, in light of the comparison and contrast of views, to change their views when another seems to them to be more viable.

Classroom Climate

The climate in a classroom where teaching for conceptual change occurs has several significant features. Both teacher and students need to respect the ideas of others in the classroom and listen carefully to them, even though they might not agree with them. It is essential for participants, without fear of sanction or ridicule, to be able to express their ideas openly, to express their disagreement with the ideas of others, and to ask for clarification of the explanations of others. Another dimension of this issue is the need to separate person and idea: to be able to critique an idea while affirming the person. One strategy for achieving this is to hide the identity of the source of an idea, e.g., by eliciting ideas in groups, collecting written ideas anonymously, or role-playing other peoples' ideas. As mentioned above, it is the teacher who must establish the classroom climate.

Next, there needs to be a common acceptance that the goal of discourse is the achievement of shared meanings about the topics under discussion. Since the diversity of initial views in the classroom needs to be recognized, achieving this goal requires a willingness to make the effort to understand others' points of view, to negotiate, and to compromise. This is a time-consuming process that can easily be subverted by tactics such as the premature closure of debate. Implicit in this process of reaching consensus is its social nature. A consensus agreement is the product of the whole group. It is more than the sum of the individual ideas people held at the start of the discussion, i.e., it has been socially constructed by the group.

Finally, the negotiated meanings need to be adopted because they make sense to the participants and not because the teacher said so. In other words, the basis for acceptance should be the rationality of the topic under consideration rather than the authority of the source of the accepted meanings, be it textbook, teacher, or individual student. An important part of achieving this is the even-handed consideration of views outlined in the guidelines above.

These features need to be operative at all times in the classroom, i.e., during the elicitation of different views and during status changing activities. They are, however, not common practice in many classrooms. Frequently, there is only one view for consideration, that of the teacher. The implicit assumption is that students' views are copies (probably imperfect) of the teacher's and are otherwise of no consequence. The teacher's view is transmitted to the students, and the only negotiation centers on whether or not the students have received this view, regardless of whether or not it makes sense to them.

Illustrations of Teaching for Conceptual Change

We illustrate the guidelines and factors discussed above with two examples drawn from one classroom, intensively studied by one of us (Beeth, 1993). These examples are not intended as definitive statements about teaching for conceptual

change--as we previously indicated other teaching approaches may also meet the same guidelines--but as an elaboration of possibilities to contribute to the debate. Before discussing the two examples we outline the context from which they are drawn.

The context

The illustrations come from a study of one year of instruction in a fifth grade classroom. (Beeth, 1993) There were 13 students (8 boys and 5 girls, aged 10-11) who lived in a predominantly white middle class community of ten thousand inhabitants within commuting distance of the nearby state capitol. All of the students participating in the study possessed characteristics typical of fifth grade students, with none requiring special services of any kind in terms of their intellectual abilities. They had 3 science periods a week.

The teacher, Sister M. Gertrude Hennessey, taught science to grades 1-6 and was vice-principal of the school, a small, parochial elementary school with one class section per grade. In other words, all of the students in this study except those who joined the school in later grades would have studied science for 5 consecutive years with Sister Gertrude. The science curriculum in the school, under her control, was coherently structured for all 6 grades. One illustration of this is the Learning Goals that were introduced in grade 1 and implemented consistently through all grades. (See Table 1)

[Table 1 about here]

While Sister Gertrude chose the topics, the detailed focus of each class was the content of students' ideas about the topic and why they held them. This ensured that elicitation, status consideration, and metacognition were central to her curriculum. She began the grade 5 school year with units on intelligibility and plausibility, terms drawn from the conceptual change model. Information presented in these units would serve the students throughout their remaining science instruction. Science

topics covered during the year included a review of the particle nature of matter (content covered in grade 4), and a unit on force and motion, a new topic for the students.

Instructional activities designed to acquaint the students with conceptual change language ultimately led to a shared understanding of how these terms would be used in this classroom. A description of the instruction that led to the consensus definition of, and examples of discourse segments containing references to, the intelligibility construct are presented below. It can not be overstated that students' ideas were the constant focus of attention in the curriculum of this classroom. A common question from Sister Gertrude following the statement of any idea was "What do you mean by [that statement]?" This apparently simple question was repeated in response to almost every statement made by a student and elicited from them the reasoning and beliefs underlying their ideas. It also required them to engage in metacognitive activity that eventually would reveal the status of an idea and components of the conceptual ecology within which that idea had meaning for them.

Another curricular decision made by Sister Gertrude that stands in contrast to much of traditional science teaching was that she never introduced current views of a scientific phenomenon, or any topic for that matter, until the students "could go no further with their ideas" (personal communication). Although she did present the students with historical accounts of scientific ideas, never did she present contemporary scientific ideas as the standard against which all ideas should be judged. Her approach was to suggest that "there are some people out there, we call them scientists, who have some ideas about [forces], and their ideas have also changed over time".

I: Developing consensus on Intelligibility

The first example describes Sister Gertrude's teaching of a complete unit to provide a sense of the general sequence of instructional activities that elicited

students' knowledge about a topic and, working with that collective knowledge, produced consensus on how a subject was understood. This was the general sequence of instruction experienced by these students regardless of whether they were studying science content or conceptual change language. The purpose of the unit described here was to develop an understanding of the term "intelligible."

The process went through various stages of students working on their own, working in small groups, and joining together for whole class discussions. Students started by independently writing a definition for "intelligible" that made sense to them. Next, the entire class worked together to produce a list of terms for "intelligible," contributing the following descriptors:

> understand, smart, clear, agree with, think about, know things, share ideas, solve, bright, clever, brilliant, wise, quick witted, capable of being understood, and understandable.

Students then formed groups of three to five to discuss what "intelligible" meant to them and to come to consensus on a meaning for the term. The pattern of alternating between small group and whole class discussion was repeated in subsequent lessons as students sought to refine their thoughts about what was and was not appropriate as a definition for "intelligible." In whole class sessions Sister Gertrude repeatedly asked the students: "Why do you think [your answer] is a good definition for intelligible?" or "Can you give me some reasons for why you think [your answer] is a good definition for intelligible?" At one point during this instruction students were asked to write a definition of "intelligible." An example written by Jack and Pete follows:

> When you explain your idea the words and sentences have to make sense. You can talk, draw, and write about your idea. Understandable and make sense have basically the same meaning. You can talk about your idea with models. When you explain your idea it has to be clear so other people can understand and make some sense with it. You can use models and analogies to represent your ideas. Your idea has to be consistent in the same situation. You can use your experiences to build your ideas. Before you can build your ideas you have to have a frameworking [sic] or a basic understanding of it. If you explain your idea by using models

they have to be clear, or make sense to other people. Your explanation has to be understandable to other people.

The teacher next presented the students with "accepted disciplinary knowledge" in the form of definitions of "intelligible" excerpted from the literature on conceptual change. The students read these excerpts and used the definition of "intelligibility" they had constructed to comment on whether or not the excerpt was intelligible to them. The students were able to read the excerpts, pausing only when authors used words unknown to them, such as epistemology or ontological. However, the students routinely stated that if they knew what words such as epistemology or ontological meant they might be able to understand what the author was trying to say. The definition that this class had no difficulty understanding, and found most closely matching their own, was written by last year's sixth grade class.

The students still needed to come to consensus on a group definition for intelligibility. Sister Gertrude used the posters of students' thoughts on "intelligible" to have them select statements that "all would agree" represented their view of "intelligible" and "some would agree" represented their view of "intelligible." Statements that were similar enough for all to agree on were transferred to a large poster entitled Group Definition for the Term Intelligible (see Table 2) as the concluding activity in the unit.

[Table 2 about here]

There are several related points worth noting about the process outlined above. The first is that throughout the unit the class provided the teacher with continually updated information on their views. They did so individually at the outset of the unit, repeatedly in small group and whole class discussions, and in the formulation of the Group Definition. Thus, among other things, this process could be regarded as one of *continual elicitation*.

Second, the class came to their consensus decision through a series of successive approximations. This allowed time for confusions to be sorted out, gaps in

understanding to be filled, and reasons supporting one view over another to be developed. In doing so, the class considered a number of different possibilities, some of which were rejected while others were accepted. In other words they were discussing the relative status of different options. This, for us, supports a view of learning not as simple and unidirectional, but as complex and cyclical, requiring repeated revisiting of all aspects of a central idea.

Next, the teacher played several different roles during the unit. She decided the central idea to be worked on, the type and sequence of instructional tasks, and when to introduce new ideas. She constantly pushed students to give reasons for what they were saying and she decided when to move on to a new idea. These are all central, controlling roles. But in other ways she deferred to students: she listened carefully and constantly to what they were saying and did not impose her ideas about intelligibility on the class. An important benefit of continually monitoring the students' understanding was that it provided a built-in safeguard against premature closure of discussion. This also served to demonstrate that the source of authority for an idea should be a reasoned argument rather than a teacher's position in the classroom.

The students played very active roles in the unit. They were constantly involved in listening to others, thinking through their own ideas, and summarizing their conclusions. All this is indicative of the degree to which they had taken responsibility for their own learning. It also supports the importance of the social nature of the construction of the consensus decision.

The final outcome--the group definition for intelligibility--provides evidence of the potential of teaching in this way. The group definition is much more than a verbal definition. It contains several parts: knowing how to determine if an idea is intelligible, knowing what can be done with a term that is intelligible, and knowing that "intelligible" can be used to refer to one's own thoughts or those of others.

II: Status negotiation: Forces acting on a falling parachute

In the following exchange one student, Don, presented his explanation of the forces acting on a toy parachute falling from the ceiling to the floor. He had drawn a dot on the white board representing the parachute, and two arrows of equal and opposite magnitude representing forces acting on the parachute. For Don, the parachute was moving in a straight line at a consistent speed, a steady pace. [A physicist would term this constant velocity.] Some of his classmates saw the motion of the parachute as an acceleration, describing it as slowing down; others didn't think it could move if the forces are equal and opposite, i.e., balanced.

Don: ok well I did the parachute and . I think that there are [two] equal forces and because it's going like in a pretty straight line and consistent speed and those two arrows are . this one's gravity and the other one is friction

This statement was followed by a very rapid sequence of questions from a variety of students trying to understand why Don found this idea plausible. All of the students speaking at this time were very confident in asking their questions, and there was a feeling in the classroom that Don's idea was about to be refuted on the grounds that the parachute was changing speed and therefore must have unbalanced forces acting on it.

Kitt: ok why do you have equal arrows? I don't think it would be moving if they had equal arrows

Don: well if [one arrow was] smaller they would be like speeding up

Kitt: well. . .

Kitt's "well. . ." strongly suggests she thought it was speeding up. A little later Kirsty (shortened to Kirs below) continued the conversation:

Kirs: ok can you repeat why you think they're equal arrows?

Don: because it's going at consistent speed and I think if they're like unequal then [the parachute] either speeds up or slows down

She introduced another example for comparison, assisted by the teacher (T).

Kirs: I'm not sure if this has a lot to do with this but if that . if that parachute was at rest what would the arrows look like? You don't think that's not at rest?

Don: well. . [it's not] at rest

Kirs: no I mean if it was

T: she's just saying in your mind . imagine this thing at rest. How would you label it?

Don: probably nothing [different]

T: nothing [different]?

Ellen had a different interpretation of Don's idea.

Ellen: then it would be floating

Don: [at rest] on the ground?

Ellen: no. In the air

Stu: well just like if it's just somewhere . if it's somewhere [in the air]

Kirsty continued with her comparison of the parachute and an object at rest.

Kirs: yeah. how would you label it if it was at rest? pretend it's sitting on this table, on a station, pretend it was just sitting there how would you label it at rest? You don't think that's what at rest is [two equal and opposite arrows]?

Don: well gravity [is one force] and the table is a force

Kitt reentered the conversation to draw another conclusion that was immediately affirmed by Rob.

Kitt: so it would be exactly like this [two equal and opposite arrows] . . . ok wouldn't it be going at a consistent speed?

Rob: it is! [said emphatically]

Don then explicitly stated the commonality he saw between objects at rest and moving at a consistent speed.

Don: at rest is also at a consistent speed

Stu: so you have two [ideas] for the same like the same sets of arrows?

Don: if a thing is at rest it's still going in a straight line at consistent speed.

This discussion left all of those present with the feeling that something important had just happened. The students started it very confident in their conceptions of the forces acting on objects at rest and in motion, in the questions they were asking each other, and in the beliefs they held about what equal and opposite arrows exemplified. They assessed the intelligibility and plausibility of Don's idea and questioned the reasons behind his idea in light of the commitments that each of them held to the consistency and generalizability with which they could argue for or against Don's position.

Several different issues are illustrated in this example. A number of different students talked explicitly about their ideas. The discussion was, among other things, an excellent elicitation exercise.

Next, the conversation in the class involved status negotiation. Students tried different approaches in questioning the plausibility of Don's explanation: Kitt queried whether the parachute was going at a consistent speed, Kirsty pointed to Don's using the same explanation (balanced forces) for the moving parachute as the class had given to objects at rest, and Ellen wondered whether the parachute wouldn't float at rest in mid air with two equal forces acting on it. Some students saw the plausibility of Don's position when they recognized what Don had been arguing for all along, viz., that an object moving at a constant velocity has the same explanation, in terms of forces, as an object at rest. Although Don spelled out this connection in his final comments, some of his classmates still did not regard "at rest" and "consistent speed" as having the same set of forces, i.e., they did not accept that Don's explanation was plausible to them. It seems clear that discussion about the status of Don's explanation was central to the class' agenda.

Third, an essential component of Don's explanation was his use of a consistency argument. Once he had recognized an essential similarity between the

falling parachute and the book on the table (neither was speeding up or slowing down) he argued for the same explanation (equal and opposite forces) by saying, in effect: consistency requires the same explanation for the same effect. We interpret this as evidence of Don's epistemological commitment to consistency.

Fourth, negotiating status is, among other things, an act of metacognition. A particular idea--Don's explanation in this case--was metaphorically laid out on the table. Kitt, Kirsty, and Ellen all commented on and critiqued different implications it held for them: they were thinking **about** Don's idea rather than thinking **with** it. This, in our view, is central to what it means to be metacognitive. In other words, this segment provides an excellent example of the kind of metaconceptual discourse that seems to be necessary in teaching for conceptual change.

Finally, the discussion conveyed an image of a serious, thoughtful, intellectual environment in the classroom. The students paid Don the compliment of listening intently to his explanation. When they disagreed with him, they focused their attention on arguments to contradict his explanation, rather than simply dismissing it or attacking Don with an *ad hominem* argument. They asked questions of Don that were typically about the plausibility of his idea: the reasons and justifications underlying his idea. Don responded to questions with a reasoned argument, a consistency argument, about how he had generalized his conception of the motion of objects and forces acting on those objects. The students' statements about science content revealed that they could, with the metacognitive skills demonstrated here, engage in discourse that facilitated their learning of science concepts. In summary, this example has provided an illustration of all of the guidelines: the explicit presentation of students' ideas, the process of negotiating the status of different ideas, the role played by students' epistemological commitments, and the extent and importance of metacognition.

Conclusions

In this article our goal has been to characterize *teaching for conceptual change*: that is, teaching explicitly aimed at helping students experience conceptual change learning. In doing this we have identified and discussed general guidelines in teaching for conceptual change; considered several important factors that facilitate using these guidelines in normal classrooms; and illustrated these guidelines using examples drawn from classroom practice.

The first guideline refers to the necessity for students' ideas to be an explicit part of classroom discourse. There are different ways to meet this guideline, dependent on the way the teacher chooses to structure the classroom. Opportunities can occur at different stages in the teaching of a unit. The first example showed how elicitation of ideas can occur individually and in groups. The second example convincingly demonstrated that this guideline can also be met in the context of teaching strategies whose primary purpose may not be elicitation but, say, constructing explanations of phenomena.

The next guideline identifies the necessity for the status of different ideas to be an explicit part of classroom discourse. In this process, students (and teachers!) are likely to find that there will be changes in the status they accord different ideas, with the status of some falling, and others rising. The second example showed several different students making suggestions that directly addressed the status of Don's explanation.

The third guideline refers to the need for explicit consideration within the curriculum of the reasons for acceptance or rejection of ideas. This guideline is a corollary of the previous one since the process of negotiating status involves a consideration of the grounds for or against the justification of an idea. This guideline ensures that these criteria are not only used but also focused on, and is

illustrated in several ways above. One of Sister Gertrude's learning goals asks: "Are your ideas consistent?" In the first example above, she constantly pressed students to identify why they responded as they did. In the second example, Don used his notion of consistency in arguing for his explanation of the falling parachute.

The final guideline identifies the metacognitive nature of status consideration. This is not, of course, independent of the previous two, but it is included because it provides another significant way of understanding what happens when people experience conceptual change learning. This point is illustrated in the first example when students discussed various statements about intelligibility drawn from the literature., and in the second example where, in effect, Don's explanation was laid out for the class to examine.

The classroom environment is an essential factor in the extent to which these guidelines are met. In the examples we have considered both teacher and students play distinctive roles that contribute to this environment of respect for each others' views, of a willingness to engage in serious discussion for extended periods of time, and of an acceptance of the goals of the classroom. It seems clear to us that most classroom environments would not support the intensity of critical examination of ideas observed: neither teachers nor students are normally willing to give the time to, or the respect for, divergent views that seems to be necessary for discourse of this nature to occur.

While we believe that the guidelines and factors discussed above are characteristic of teaching for conceptual change, they are not all that is necessary. There are features, not considered here, that conceptual change teaching shares with other forms of teaching. It is also the case that an incomplete description of the teacher's role was presented above. The examples point to different things she did, but they should not be construed as describing all that she did. Also, the guidelines themselves are not detailed enough: putting them into practice requires the

development of many different activities related to the topic being considered and the ideas that students bring with them.

Each of the guidelines and factors may not, in isolation, seem very different from current teaching practice. After all, dedicated teachers over the years have developed science activities and employed teaching strategies that have challenged many students and facilitated much science learning: without doubt, teaching for conceptual change benefits from this huge base of expertise. Some teachers may also feel that we are simply providing names for common practices that they have known and used, so why make any fuss about them? While this is may be so (we have had the same reaction on occasion) we believe that in combination with each other, these guidelines and factors do represent a change in current practice. Furthermore, it is a change that is not incremental; far from it. In comparison with most current teaching, teaching for conceptual change is a radically different enterprise.

A final question remains: Why teach for conceptual change? Why make the effort to go through the extensive transformation that this entails? One type of answer is a negative one that arises from a dissatisfaction with the *status quo*. With so many students leaving science classes with little more than a veneer of vacant vocabulary, there is plenty of motivation for finding a better way. Teaching for conceptual change is one of a range of different possibilities. A second type of answer is a positive one that looks for desirable outcomes. The examples presented above demonstrate a quality of discussion, a maturity of approach, a depth of understanding that would be impressive at a freshman college level. That the discussion was conducted by a group of fifth grade students is, in our opinion, quite remarkable. If this is representative of potential learning outcomes, it seems reason enough to teach for conceptual change.

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Table 1: The Teacher's Learning Goals

1. Can you state your own ideas?
2. Can you talk about why you are attracted to your ideas ("the what as well as the why")?
3. Are your ideas consistent?
4. Do you realize the limitations of your ideas and the possibility they might need to change?
5. Can you try to explain your ideas using physical models?
6. Can you explain the difference between understanding an idea and believing in an idea?
7. Can you apply intelligibility (I) and plausibility (P) [and fruitfulness (F)] to your own ideas?

Note: Goals 1 and 2 are presented to students when they enter Sister Gertrude's classroom as first grade students (ages 5 - 6). The remaining goals are added until by fourth grade (ages 9 - 10) the entire list has been presented.

Table 2: Group Definition for the Term Intelligible

- The term intelligible can be used to describe:
  (1) my own ideas
  (2) someone else's ideas/other people's ideas

- When I say that an idea is intelligible to me that means I think I understand the idea.

- There are two ways to help me decide if I understand an idea:
  (1) I must decide if I understand what the words, sentences, and ideas are about or what they mean.
  (2) I must decide if the words and ideas behind the words make sense to me.

- When I decide that I understand an idea then I should be able to:
  (1) find ways of representing my ideas to others by: using drawings, illustrations; talking about or explaining my ideas to others; use analogies or give examples to explain or make my ideas clear to others.